

Evaluation Boards for Single, Dual, and Quad Operational Amplifiers

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INTRODUCTION

This application note describes evaluation boards for single, dual, and quad operational amplifiers whose pin-outs follow industry standard amplifier sockets. These printed circuit boards were designed to provide quick and easy evaluation of precision and medium-speed (gain-bandwidth products < 10 MHz) operational amplifiers in inverting and noninverting applications. Furthermore, provisions have been made on the boards to evaluate operational amplifier capacitive loading effects using inside-the-loop or outside-the-loop capacitive load compensation techniques.

Figure 1 illustrates the basic circuit configuration for each of the evaluation boards. Provisions have been made to the board for optional components in addition to the required feedback resistors and power supply bypass capacitors. For example, if the application requires evaluating amplifier inside-the-loop capacitive load compensation, then R_X and C_X can be used. If an external outside-the-loop compensation technique is used, a jumper is substituted for R_X , C_X is removed completely,

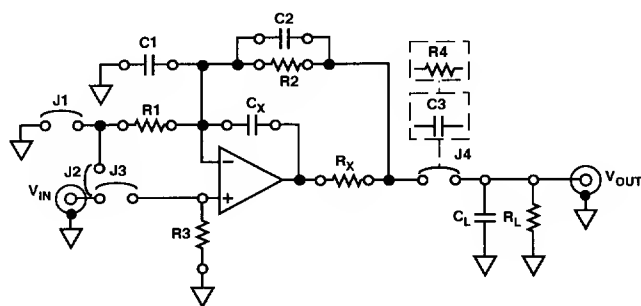


Figure 1. Complete Circuit Schematic and Connections for the Operational Amplifier Evaluation Board

and R_4 is inserted in series with the amplifier output. Jumpers and open circuits are used throughout the evaluation board as necessary to provide most any circuit configuration. For example, if the application requires an ac-coupled output voltage, then C_3 can be substituted for J_4 .

Power Supply Connections

Power supply connections for the evaluation boards are shown in Figure 2. For optimal low frequency power supply filtering, C_{P1} and C_{P2} should be $10\ \mu\text{F}$ (or larger) electrolytic capacitors. These capacitors should be of the tantalum type with working voltages greater than $25\ \text{V}$ in $\pm 15\ \text{V}$ applications. C_{P3} and C_{P4} are $0.1\ \mu\text{F}$ ceramic capacitors and are located in close proximity to the amplifier's supply pins for optimal high frequency filtering. They, too, should exhibit working voltages greater than or equal to $25\ \text{V}$. For additional filtering, provisions have been made for the use of resistors in series with the amplifier power supply leads (R_{S+} and R_{S-}). To avoid input/output voltage headroom issues, voltage drops due to these resistors should be limited to less than $0.1\ \text{V}$. If these resistors are not needed, then $0.4''$ wire jumpers should be used.

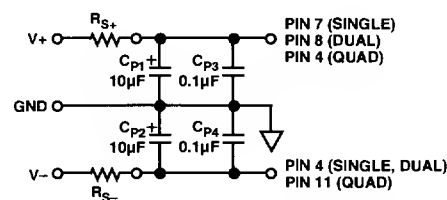


Figure 2. Power Supply Connections and Bypassing Components for the Operational Amplifier Evaluation Board

Noninverting and Inverting Amplifier Configurations

Configuring the evaluation board for noninverting amplifier applications is straightforward and is shown in Figure 3. In this configuration, jumper J1 connects R1 to GND, jumper J2 couples the input signal to the noninverting terminal of the amplifier, C_x is removed altogether, and jumper J3 is substituted for R_x. R3 can be used as a termination/input bias current compensation resistor, if required. The circuit's signal transfer equation, including the effects of finite amplifier open-loop gain, is given by Equation 1:

$$\frac{V_{OUT}}{V_{IN}} = 1 + \frac{R2}{R1} \left[\frac{1}{1 + \frac{1}{A_{OL}} \left(1 + \frac{R2}{R1} \right)} \right] \quad \text{Eq. 1}$$

where A_{OL} = Amplifier open-loop gain, in Volts per Volt (V/V);

and

R2, R1 = Amplifier feedback network resistors, in ohms

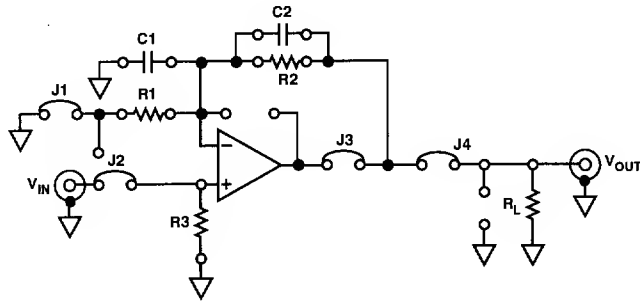


Figure 3. Circuit Configurations for Noninverting Amplifier Applications

For inverting amplifier applications, the circuit configuration is shown in Figure 4. The input signal is applied to R1 through J1; thus, the circuit's transfer equation is given by Equation 2:

$$\frac{V_{OUT}}{V_{IN}} = -\frac{R2}{R1} \left[\frac{1}{1 + \frac{1}{A_{OL}} \left(1 + \frac{R2}{R1} \right)} \right] \quad \text{Eq. 2}$$

where A_{OL} , R2, and R1 have been previously defined.

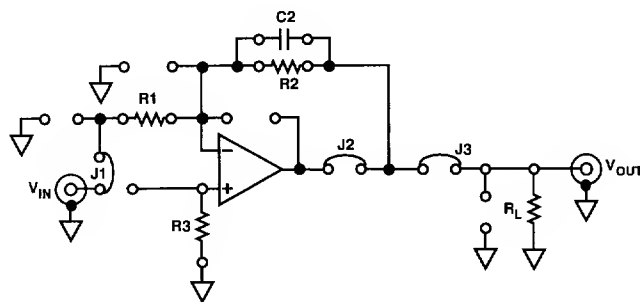


Figure 4. Circuit Connections for Inverting Amplifier Applications

Filter capacitors C2 and C1 can be used to tailor the response of the amplifier circuit. For either noninverting or inverting applications, capacitor C2 works with R2 to bandlimit the amplifier's high frequency response and places a pole in the response at:

$$f_P = \frac{1}{2\pi \times R2 \times C2} \quad \text{Eq. 3}$$

On the other hand, capacitor C1 works with R1 to introduce a zero in the amplifier response. The location of this low frequency corner is given by Equation 4:

$$f_Z = \frac{1}{2\pi \times R1 \times C1} \quad \text{Eq. 4}$$

Note, capacitor C1 should be used only in noninverting amplifier configurations, for, if it were used in inverting amplifier applications, it would appear in parallel with the input capacitance of the operational amplifier and could cause instability.

In many applications, it is often necessary to evaluate the total output voltage error of an amplifier configuration due to amplifier input offset voltage, common-mode rejection, input bias and offset currents, and open-loop gain. Using either the noninverting or the inverting amplifier configuration, the total output voltage error of an amplifier due to these parameters is given by Equation 5:

$$V_{OUT} = \left(\frac{1}{1 + \frac{1}{A_{OL}} \left(1 + \frac{R2}{R1} \right)} \right) \times \left[\left(V_{OS} + \frac{V_{CM}}{CMRR} \right) \left(1 + \frac{R2}{R1} \right) + \left(I_B - \frac{I_{OS}}{2} \right) \times R2 \right] \quad \text{Eq. 5}$$

where A_{OL} = Amplifier open-loop gain, in V/V;

V_{OS} = Amplifier input offset voltage, in volts;

V_{CM} = Applied input common-mode voltage, in volts;

$CMRR$ = Amplifier common-mode rejection ratio, in V/V;

I_B = Amplifier input bias current, in amperes;

I_{OS} = Amplifier input offset current, in amperes;

and

R2, R1 = Amplifier feedback network resistors, in ohms.

In applications where large source/feedback resistors or amplifiers with large input bias currents are used, then R3 should be set to the parallel combination of R1 and R2.

Amplifier Capacitive Load Compensation

As with any operational amplifier, care must be taken when driving capacitive loads. Many operational amplifier data sheets now provide information with regard to amplifier output voltage overshoot versus capacitive load. In those cases where little or no information is provided by the manufacturer on this issue, the circuit configuration shown in Figure 5 can be used to evaluate an amplifier's capacitive load driving capability using an inside-the-loop compensation technique. This technique works equally well for inverting or noninverting applications where the closed-loop circuit gain is greater than unity. Unity-gain circuit configurations for inside-the-loop capacitive load compensation are a special case and will be mentioned shortly.

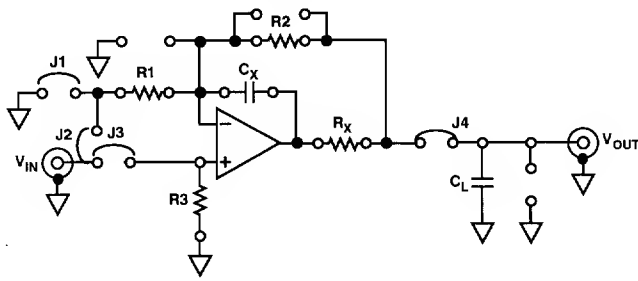


Figure 5. Amplifier Circuit Connections for an Inside-the-Loop Capacitive Load Compensation Technique

Load capacitance reacts with an amplifier's open-loop output resistance (R_O) to produce an additional pole in the feedback path. If the additional pole falls within the loop-gain response of the amplifier, then the added phase shift produced by this pole will introduce response ringing and can even cause oscillation.

As shown in the figure, R_X is used to isolate the amplifier's output stage from the capacitive load, and C_X is used to provide a secondary bypass feedback loop which controls the amplifier's loop-gain response at high frequencies. Although the selection for R_X and C_X is empirical in the final analysis, Equations 6 and 7 can be used to select initial values for R_X and C_X :

$$R_X = \frac{R_O \times R1}{R2} \quad \text{Eq. 6}$$

$$C_X = \left(1 + \frac{1}{|A_{CL}|}\right) \times \left(\frac{R2 + R1}{R2^2}\right) \times C_L \times R_O \quad \text{Eq. 7}$$

where R_O = Amplifier high-frequency, open-loop output resistance, in ohms;

A_{CL} = Amplifier closed-loop gain, in V/V;

C_L = Load capacitance, in farads;

and

$R1, R2$ = Amplifier feedback network resistances, in ohms.

These equations are valid for either inverting or non-inverting applications. Note, that R_O (amplifier open-loop output resistance) can be determined empirically or from amplifier data sheets. If graphs for amplifier output impedance versus frequency are provided, then R_O is equal to the value of the amplifier's closed-loop output impedance at the open-loop, unity-gain cross-over frequency. Note, C_X is a product of the circuit's closed-loop gain, the amplifier's high frequency output impedance, and the load capacitance.

Two important points with regard to this technique require mention: First, R_X cannot be made arbitrarily large because the voltage drop across R_X detracts from the amplifier's output voltage range. Second, this technique reduces the bandwidth of the circuit and is determined by Equation 8:

$$f_{3dB} = \frac{1}{2\pi \times R2 \times C_X} \quad \text{Eq. 8}$$

Unity-gain noninverting amplifier applications are a special case. Since $R1$, shown in Figure 5, is not used in voltage buffer applications, Equation 7 cannot be used to determine an initial value for C_X . In these cases, an approximation can be made for C_X and is given by Equation 9:

$$C_X = \frac{2 \times R_X \times C_L}{R2} \quad \text{Eq. 9}$$

where $R_X = R_O$, C_L , and $R2$ have been previously defined.

In applications where an inside-the-loop compensation technique cannot be used, as in the case for current-feedback operational amplifiers, outside-the-feedback loop compensation techniques substitute $R4$ for the jumper wire at the output of the amplifier, as shown in Figure 6. Note, capacitor C_X is removed completely and a jumper wire is used in place of R_X . The value for $R4$ is empirical, as it depends on the choice of amplifier, capacitive load, and the closed-loop circuit gain. Some amplifier data sheets (References [1] and [2]) provide information regarding outside-the-loop capacitive load compensation for those specific devices. However, in general, drawbacks to this approach are: limited available slew rate (amplifier short-circuit current determines output voltage slew rate), output voltage swing limitations ($R4$ forms a signal attenuator with R_L), and signal bandwidth limitations ($R4$ and R_L form a low-pass filter with C_L).

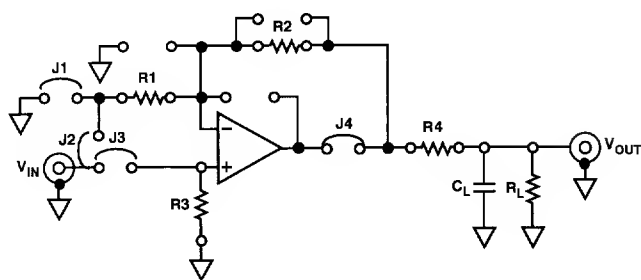


Figure 6. Amplifier Circuit Connections for an Outside-the-Loop Capacitive Load Compensation Technique

Evaluation Board Application Caveats

These evaluation boards were designed for engineering evaluations of single, dual, and quad operational amplifiers. As such, these boards were intended for engineering laboratory environments where ambient temperatures range from +20°C to +50°C. They are not designed for heavy-duty production or incoming device qualification where these boards could be exposed to wide operating temperatures. In fact, since the layouts of the circuits are not isothermal, their use in evaluating operational amplifier input offset voltage drift performance over temperature should be carefully considered.

As previously mentioned, the evaluation board layouts have not been optimized for high speed voltage- or current-feedback amplifiers that exhibit gain-bandwidth products (GBWP) > 10 MHz. On the other hand, these boards can be used in applications where signal rates of change are less than 50 V/μs.

Lastly, these boards should also not be used to evaluate very low input bias current ($I_B < 50$ pA) and electrometer-grade operational amplifiers that require very clean printed circuit boards, Teflon component standoffs, and conformal coatings to minimize parasitic leakage currents.

Circuit Board Layout and Construction Considerations

Figures 7, 8, and 9 illustrate the layouts of the single, dual, and quad operational amplifier evaluation boards. Although not shown to scale, the finished dimensions of the boards are 3.15 inches by 3.15 inches for the single op amp evaluation board, 3.4 inches by 3.5 inches for the dual op amp evaluation board, and 3.8 inches by 4.65 inches for the quad op amp evaluation board. In Figure 1, jumper wires J1, J2, and J3 are mounted into the board on a 0.3" center-to-center spacing ("centers"), and jumper wire J4 is mounted on 0.4" centers. Resistors used in the evaluation board should be of the metal-film type and are mounted into the board on 0.4" centers. Signal filter capacitors, C1 and C2, and supply bypass capacitors, C_{P3} and C_{P4} , are mounted into the evaluation board on 0.2" centers. Low frequency bypass capacitors, C_{P1} and C_{P2} , are mounted into the boards on 0.1" center-to-center spacing.

Pin sockets are flush-mounted into the board, for ease of component interchangeability. They are, however, optional in those applications where higher speed performance is necessary. To avoid unintentional

resonant-tuned circuits, components used in the evaluation board should have short leads, no longer than that required for insertion directly into the board or into the pin sockets. Lead forming tools are useful to help keep resistor component lead lengths short: a lead 0.1" long can exhibit a self-inductance of 2 nH.

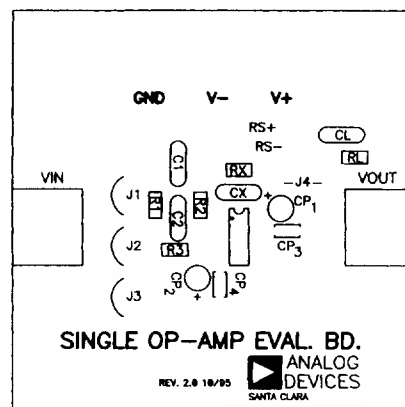


Figure 7a. Single Op Amp Evaluation Board Topside Silkscreen (Not to Scale)

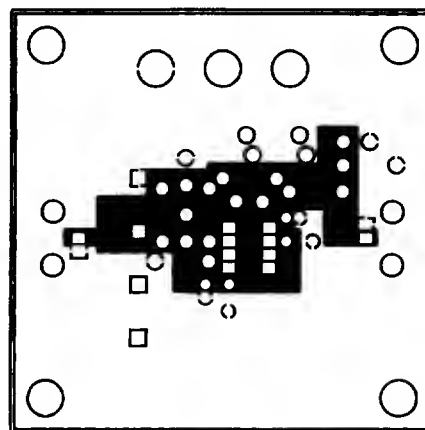


Figure 7b. Single Op Amp Evaluation Board Topside Metalization (Not to Scale)

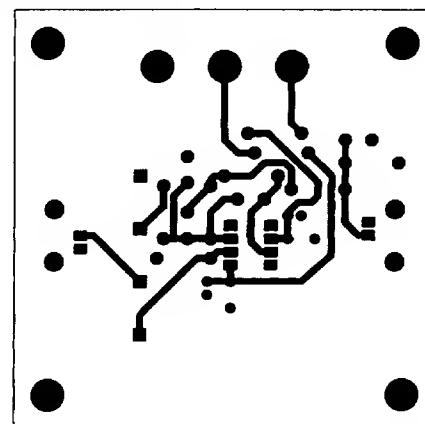


Figure 7c. Single Op Amp Evaluation Board Backside Metalization (Not to Scale)

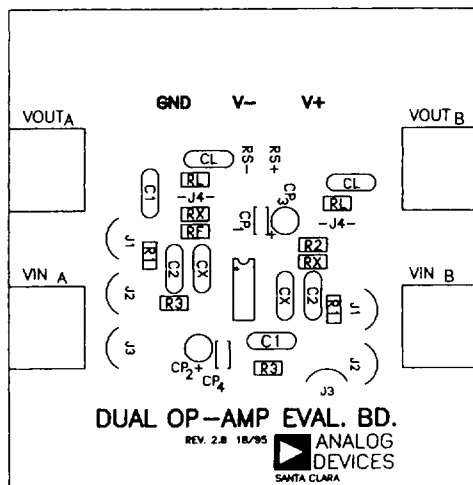


Figure 8a. Dual Op Amp Evaluation Board Topside Silkscreen (Not to Scale)

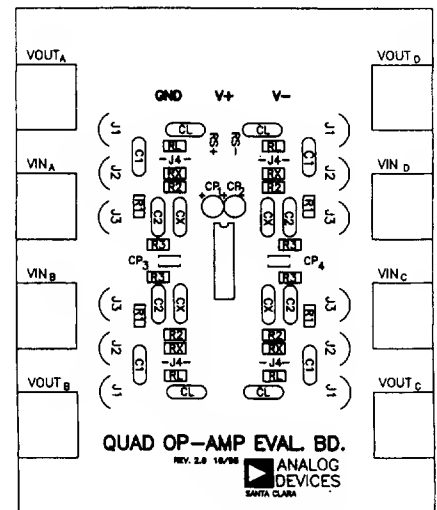


Figure 9a. Quad Op Amp Evaluation Board Topside Silkscreen (Not to Scale)

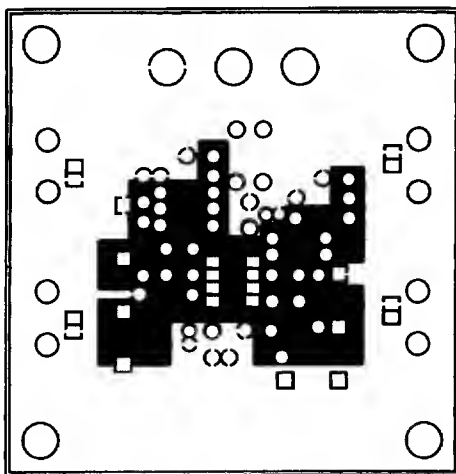


Figure 8b. Dual Op Amp Evaluation Board Topside Metalization (Not to Scale)

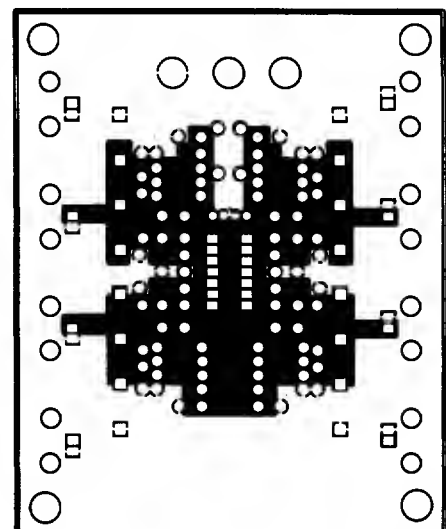


Figure 9b. Quad Op Amp Evaluation Board Topside Metalization (Not to Scale)

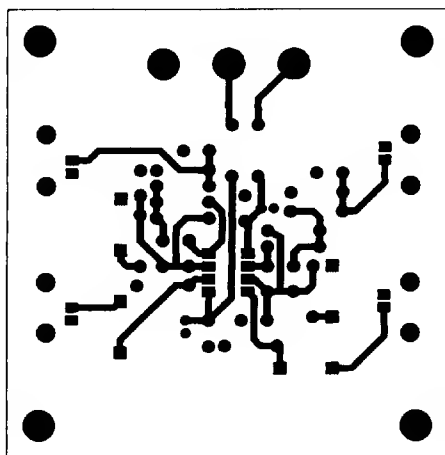


Figure 8c. Dual Op Amp Evaluation Board Backside Metalization (Not to Scale)

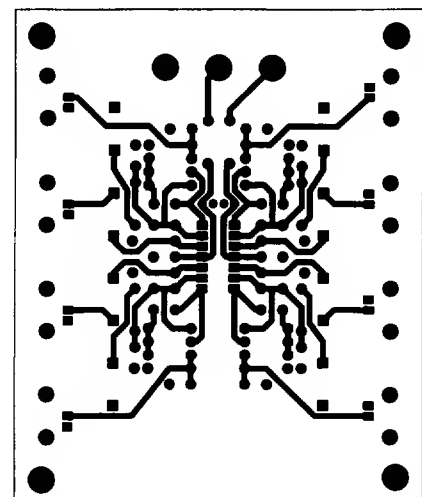


Figure 9c. Quad Op Amp Evaluation Board Backside Metalization (Not to Scale)

An example of a complete evaluation board is illustrated in Figure 10. The circuit is constructed around the OP279, a single-supply, rail-to-rail input/output operational amplifier with high output current drive. Each of the amplifiers in the circuit was configured for a gain of -10 using 909 Ω for R2 and 100 Ω for R1.

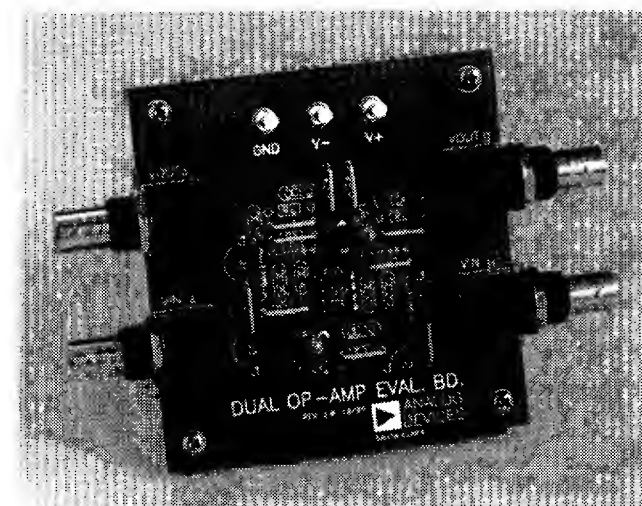


Figure 10. Dual Op Amp Evaluation Board Configured for the OP279 in a Gain-of-10 Inverting Application

Acknowledgments

The author wishes to acknowledge the efforts of Louis Agot, PRA engineering technician, who designed the board layouts, routed, built, and tested the prototypes.

Operational Amplifier Evaluation Board Materials List

For the single operational amplifier evaluation board:

Description	Quantity
Evaluation Board	1
Pin Sockets ¹	36
BNC Connectors, Female ²	2
Double Turret Terminals ³	3

For the dual operational amplifier evaluation board:

Description	Quantity
Evaluation Board	1
Pin Sockets	60
BNC Connectors, Female	4
Double Turret Terminals	3

For the quad operational amplifier evaluation board:

Description	Quantity
Evaluation Board	1
Pin Sockets	114
BNC Connectors, Female	8
Double Turret Terminals	3

NOTES

¹ All pin socket quantities include those required for the power supply bypass components. Pin sockets are available from MIL-MAX (Part No. 1401-0-15-01-30-02-10-0). MIL-MAX can be contacted at (516) 922-6000.

² Right angle BNC connectors are available from A/D Electronics (Part No: 560-401-00). A/D Electronics can be contacted at (206) 851-8005.

³ Double turret terminals are available from Concord Electronics (Part No. 10-204-2-01). Concord Electronics can be contacted at (212) 777-6571.

REFERENCES

1. "AD9617 Low Distortion, Precision Wideband Operational Amplifier Data Sheet." Order number: C1353-10-10/89.
2. "AD811 High Performance Video Operational Amplifier Data Sheet." Order number: C1592-24-11/91.

These data sheets can be requested directly from the Analog Devices Literature Center at (800) 262-5643, Option 2, or at (617) 461-3392.